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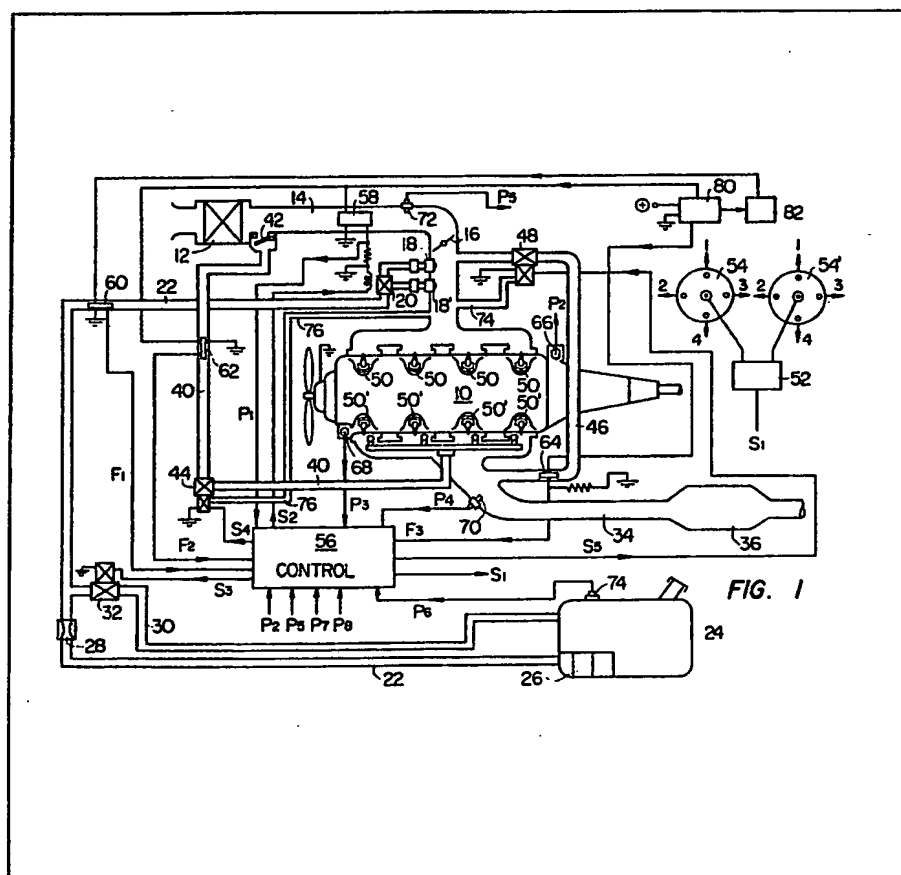
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(54) ELECTRONICALLY CONTROLLED INTERNAL COMBUSTION ENGINE FUEL INJECTION SYSTEM

(57) An electronically controlled internal combustion engine system comprises fuel injection nozzles (18, 18') opening into an induction passage (14), an air flow rate sensor (58) disposed in the induction passage, and a fuel flow rate sensor (60) disposed in a fuel passage (22) which is provided with a valve (32) to regulate fuel supply rate. Both flow rate sensors (58, 60) are of a type which produce corona discharges in the fluid flow and detect the movement of ions as an

indication of the velocity of the fluid flow. An electronic control circuit (56) controls the fuel supply rate regulation valve (32) in accordance with the outputs of the two flow rate sensors (58, 60) such that the mixing ratio of fuel to air agrees with a target value. The system also has a sensor (62) of air flow to the exhaust gas reactor (36) which air flow is intermittent and passes through reed valve (42). Additionally the quantity of exhaust gas recirculated is sensed at (64) and controlled by servo-valve (48) (see Figure 7). Each cylinder is provided with two sparking plugs (50, 50') to ensure combustion at high levels of exhaust gas recirculation.



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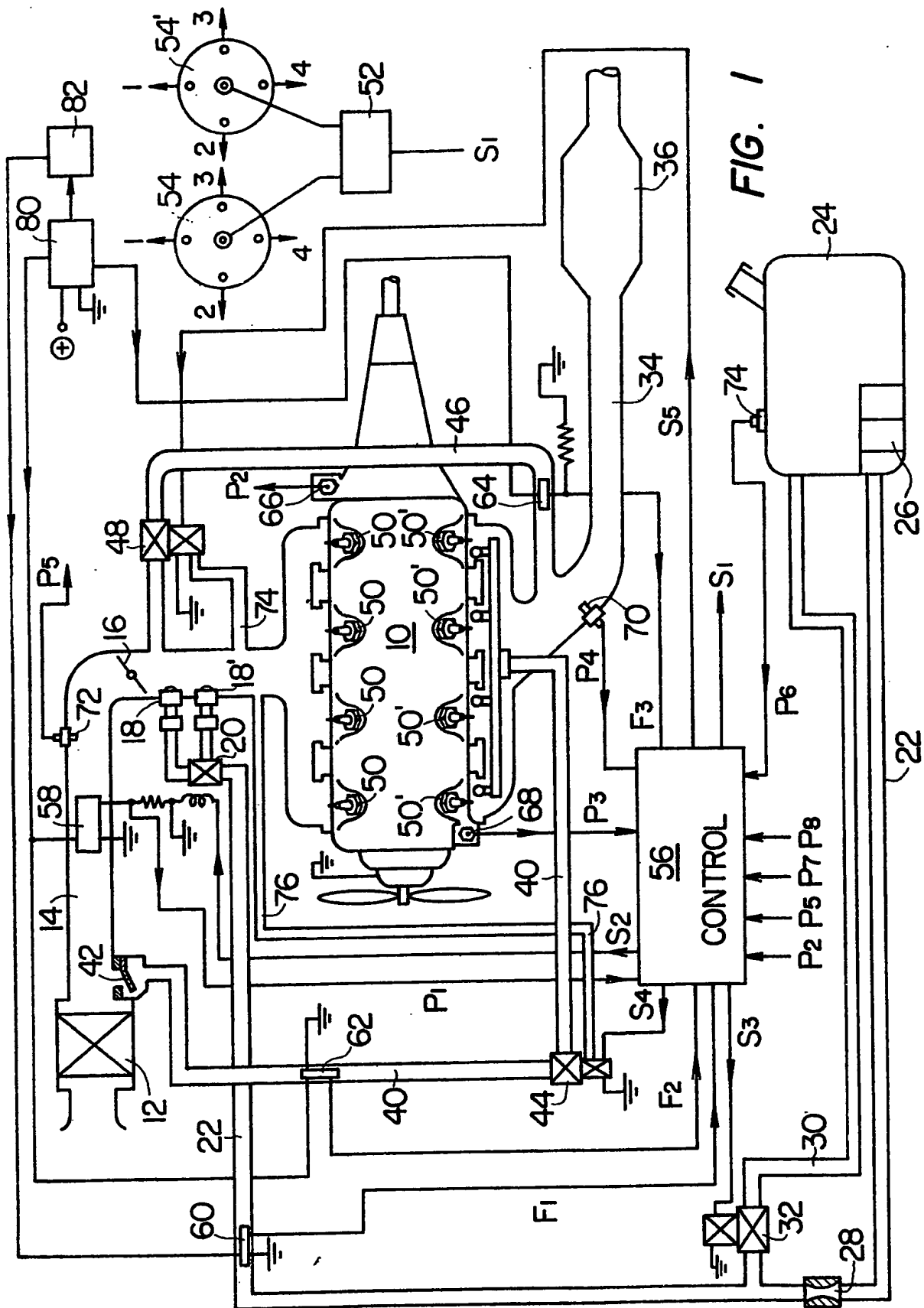


FIG. 2

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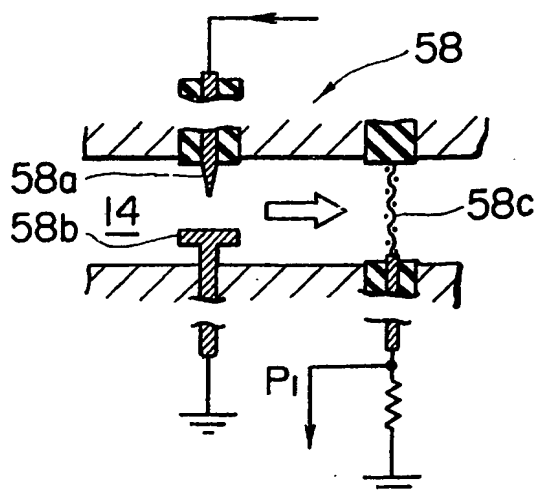


FIG. 4

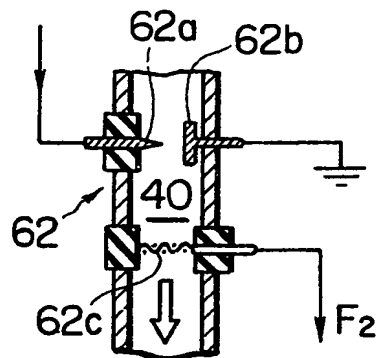


FIG. 3

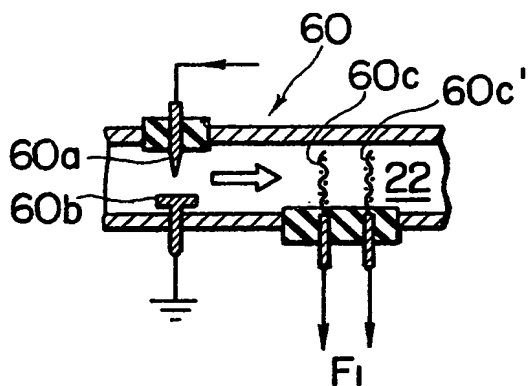


FIG. 5

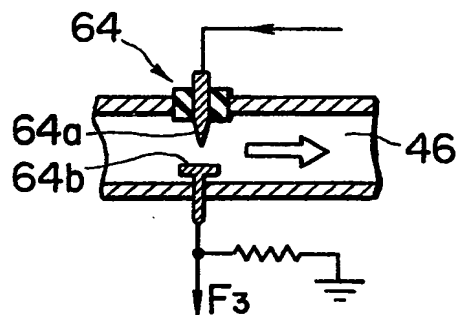


FIG. 6

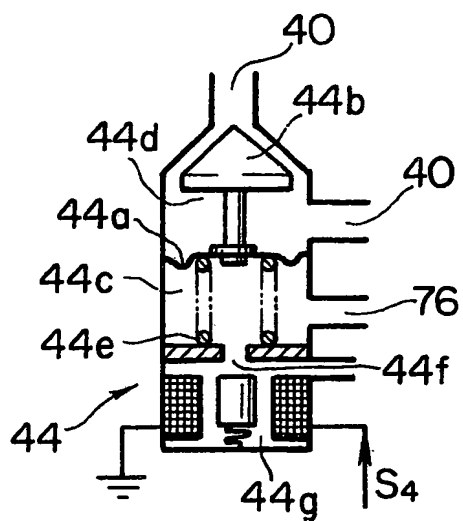
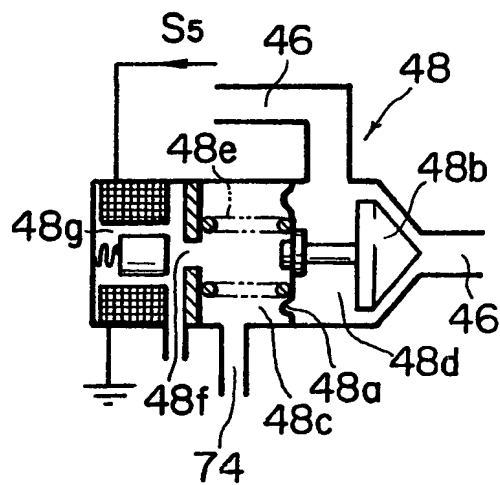


FIG. 7



SPECIFICATION

ELECTRONICALLY CONTROLLED
INTERNAL COMBUSTION ENGINE SYSTEM

This invention relates to an electronically controlled internal combustion engine system including a subsystem to precisely control the rate of fuel injection, or mixing ratio of air to fuel, wherein both the air flow rate in the induction passage and the fuel flow rate in the fuel supply passage are detected by means of flow rate sensors of a type detecting a movement of ions formed by corona discharge in a fluid flow as an indication of the flow velocity.

As regards internal combustion engines particularly for automotive uses, precise regulation of the mixing ratio of air to fuel to a target value is universally accepted as of key importance to success in lessening noxious components of the exhaust gas and producing improvements on the specific fuel consumption. Various methods have been proposed recently for precise control of the air/fuel ratio, but every one of them, at least these proved to be feasible, is still unsatisfactory in certain respects.

In the case of fuel systems utilizing a carburetor in which the rate of fuel supply depends on the velocity of air passing through a venturi section, it is difficult to maintain a constant level of accuracy in the control of air/fuel over the entire range of the engine speed. The control of air/fuel ratio can be accomplished with improved accuracy by the employment of an electronically controlled fuel injection system in place of a carburetor, but even in this case there occurs an appreciable deviation of air/fuel ratio from the aim of the control under certain operating conditions of the engine because the injection of fuel is made without measuring an actual rate of fuel supply to the engine.

To achieve more accurate control of air/fuel ratio, it has already been put into practice to make a feedback control by utilizing an oxygen sensor to detect the oxygen content of the exhaust gas as an indication of the air/fuel ratio of a combustible mixture actually supplied to the engine. However, a control system of this type involves a problem that the response of the control system to fluctuations in air/fuel ratio is not quick enough to ensure a good driveability during operation of the engine under transient conditions since feedback is made from the exhaust system with a considerable time lag from the occurrence of a fluctuation of air/fuel ratio in the intake system.

An engine system according to the invention comprises an internal combustion engine including an induction passage provided with a throttle valve which is linked with an accelerator, an exhaust passage, at least one fuel injection nozzle opening into the induction passage at a section downstream of the throttle valve and a fuel passage connecting the fuel injection nozzle to the fuel tank. A first flow rate sensor is disposed in the induction passage to detect the flow rate of air. An

electrically-operated valve is associated with the fuel passage to regulate the rate of fuel supply to the injection nozzle, and a second flow rate sensor is disposed in the fuel passage to detect a realized flow rate of fuel. Both the first and second flow rate sensors are of a type which brings about corona discharge in a fluid flow and detects a movement of ions formed by the corona discharge as an indication of the velocity of the fluid flow. The engine system further comprises a high voltage source connected to the first and second flow rate sensors and an electronic control circuit which controls the fuel supply rate regulation valve based on the outputs of the first and second flow rate sensors such that the ratio of the fuel flow rate detected by the second sensor to the flow rate of air detected by the first sensor agrees with a target value.

This engine system may additionally comprise a reactor which occupies a portion of the exhaust passage to oxidize carbon monoxide and hydrocarbons contained in the exhaust gas in combination with a secondary air admission passage which is connected to the exhaust passage and provided with an electrically-operated flow control valve and a third flow rate sensor, and/or an exhaust gas recirculation passage which interconnects the exhaust passage to the induction passage at a section downstream of the throttle valve and is provided with an electrically-operated flow control valve to recirculate a portion of the exhaust gas to the induction passage and a fourth flow rate sensor. In this case, both the third and fourth flow rate sensors are of the same type as the first and second flow rate sensors and are connected to the aforementioned high voltage source, and the flow control valves are controlled by the aforementioned control circuit primarily based on the outputs of the third and fourth sensors, respectively.

Since the injection of fuel in an engine system according to the invention is controlled based on an actual rate of air feed to the engine and an actual rate of fuel feed resulting from the control, the mixing ratio of fuel to air can be regulated to a target value with high accuracy and good responsiveness. As a consequence improvements can be produced on the performance of the engine in various aspects such as specific fuel consumption, driveability and the composition of the exhaust gas. When the engine is provided with a secondary air supply system and/or an exhaust gas recirculation system, highly efficient lessening of noxious components of the exhaust gas can be achieved without impairing the engine performance since a direct feedback is made in controlling either of the secondary air supply rate and the exhaust gas recirculation rate. Flow rate sensors of the aforementioned corona discharge type are high in accuracy, good at responsiveness, small in size and free from mechanically moving parts. The provision of two to four flow rate sensors of this type to an engine system according to the invention does not significantly complicate the construction of the system or significantly

raise the cost of the system because each flow rate sensor is a simple device and a single high voltage source can be utilized common to all the flow rate sensors.

Fig. 1 is a diagrammatic presentation of an electronically controlled engine system as an embodiment of the invention;

Fig. 2 shows the construction of an air flow rate sensor used in the system of Fig. 1;

Fig. 3 shows the construction of a fuel flow rate sensor used in the system of Fig. 1;

Fig. 4 shows the construction of a flow rate sensor used in the system of Fig. 1 to detect the quantity of admitted secondary air;

Fig. 5 shows the construction of a flow rate sensor used in the system of Fig. 1 to detect the quantity of recirculated exhaust gas;

Fig. 6 shows the construction of a secondary air control valve used in the system of Fig. 1; and

Fig. 7 shows the construction of an exhaust gas recirculation control valve used in the system of Fig. 1.

Fig. 1 illustrates the application of the invention to a four-cylinder internal combustion engine 1 for automotive use. An induction passage 14 for this engine 10 comprises an air cleaner 12 and a throttle valve 16 linked with an accelerator (not shown) in the usual manner. Downstream from the throttle valve 16, two fuel injection nozzles 18 and 18' open into the induction passage 14 to introduce fuel into air flowing through the passage 14 thereby to prepare an appropriately proportioned air-fuel mixture. The two fuel injection nozzles 18 and 18' are both connected to a fuel tank 24 via a selector valve 20 by a common fuel passage 22. The fuel tank 24 is provided with a pressure-regulator pump 26. The fuel passage 22 comprises a metering orifice 28, and a fuel return passage 30 branches from the fuel passage 22 at a section downstream from the orifice 28. The fuel return passage 30 is provided with a control valve 32 which can vary the amount of fuel returned through the passage 30, so that the rate of fuel feed to the injection nozzles 18, 18' can be varied without the need of controlling the delivery pressure of the pump 26.

In this engine system, the fuel injection nozzles 18, 18' each make a continuous injection of fuel so long as fuel is supplied thereto, and the rate of fuel feed to the engine 10 is controlled by means of the control valve 32 and the selector valve 20. The reason for the provision of two injection nozzles 18, 18' is that the use of only one fuel injection nozzle of this type brings about insufficient atomization of fuel under low fuel-feed rate conditions. There is a difference in cross-sectional area between these two injection nozzles 18, 18', and the selector valve 20 is employed to selectively put into work one of these injection nozzles 18, 18' depending on the air flow rate in the induction passage 14. For example, the difference in cross-sectional area between these injection nozzles 18, 18' is made such that the injection nozzle 18 alone is utilized in intermediate and high speed ranges while the injection nozzle 18' alone in a low speed

range. According to an alternative design, the two injection nozzles 18, 18' may be utilized simultaneously in intermediate and high speed ranges, but only one of them in a low speed range.

An exhaust passage 34 for the engine 10 is provided with a reactor 36 for purification of the exhaust gas, for example a reactor containing a catalyst effective for oxidation of carbon monoxide and hydrocarbons in the exhaust gas. To introduce air into the exhaust gas before its arrival at the reactor 36, a secondary air conduit 40 branches from the induction passage 14 in the proximity of the air cleaner 12 and joins the exhaust passage 34 at a section upstream of the reactor 36. At the junction with the induction passage 14, the secondary air conduit 40 is provided with a reed valve 42 which opens and closes intermittently in compliance with pulsation of exhaust gas pressure in the exhaust passage 34. In addition, a flow control valve 44 is associated with the secondary air conduit 40 at an intermediate section.

An exhaust gas recirculation passage 46 in the form of a conduit branches from the exhaust passage 34 at a section upstream of the reactor 36 and joins the induction passage 14 at a section downstream of the throttle valve 16 to recirculate a portion of the exhaust gas to the combustion chambers of the engine 10 thereby to suppress the formation of nitrogen oxides. The exhaust gas recirculation passage 40 is provided with a flow control valve 48 for the purpose of normally maintaining a constant rate of exhaust gas recirculation (the rate of exhaust gas recirculation means the proportion of the quantity of the recirculated exhaust gas to the quantity of air admitted into the engine 10).

In the illustrated embodiment of the invention, the engine 10 comprises two identical and simultaneously functioning spark plugs 50 and 50' for each combustion chamber with a principal object of realizing a stable and relatively fast combustion of an air-fuel mixture which is diluted with a relatively large amount of recirculated exhaust gas. Accordingly the ignition system of this engine has two distributors 54 and 54', one for the spark plugs 50 and the other for the spark plugs 50'. Indicated at 52 is a high voltage generator in the ignition system.

This engine system comprises an electronic control circuit 56 which controls the function or operation of the selector valve 20 for the fuel injection nozzles 18, 18', fuel supply control valve 32, secondary air control valve 44 and exhaust gas recirculation control valve 48 as will be described later in detail. The high voltage generator 52, too, is under the control of the control circuit 56 so as to realize an optimum ignition timing in accordance with operating conditions of the engine 10.

A flow rate sensor 58 installed in the induction passage 14 provides an electrical signal P_1 indicating an actual rate of air feed to the engine 10 as a primary input to the control circuit 56. Fig. 1 shows that the flow rate sensor 58 is positioned.

upstream of the throttle valve 16, but alternatively this sensor 58 may be positioned between the throttle valve 16 and the fuel injection nozzles 18, 18'.

5 Some other parameters of the engine operating condition are measured by suitable sensors to be utilized as additional inputs to the control circuit 56. By way of example, the engine system of Fig. 1 includes a crank angle sensor or engine speed
10 sensor 66 which provides a signal P_2 , temperature sensor 68 to detect the engine temperature represented by the temperature of cooling water (signal P_3), sensor 70 to measure the exhaust gas temperatures (signal P_4), sensor 72 to measure the
15 temperature of air admitted into the induction passage 14 (signal P_5) and sensor 74 which detects the specific weight of fuel in the tank 24 (signal P_6). In Fig. 1, auxiliary inputs P_7 and P_8 to the control circuit 56 represent humidity and
20 atmospheric pressure, respectively.

To provide to the control circuit 56 a feedback signal F_1 representing an actual rate of fuel supply to the engine 10 through the injection nozzles 18, 18', a flow rate sensor 60 is installed in the fuel
25 passage 22 at a section downstream of the junction of the fuel return passage 30 and the fuel supply passage 22.

As a feature of an engine system according to the invention, both the air flow rate sensor 58 and
30 the fuel flow rate sensor 60 are of a type which brings about corona discharge in a fluid subject to measurement to cause partial ionization of the fluid and produces an electrical signal representing the flow rate of the fluid by detecting
35 a movement of ions formed by the corona discharge. A high voltage needed for corona discharge is supplied to both of these new flow rate sensors 58 and 60 from a high voltage generator 80. There are variations in the
40 construction of this type of flow rate sensor, and in certain cases the high voltage generator 80 is not directly connected to this type of sensor but is connected to a pulse generator 82 which supplies a high voltage pulse to the sensor.

45 In addition, the engine system of Fig. 1 comprises a flow rate sensor 62 which is installed in the secondary air passage 40 and provides a feedback signal F_2 indicating an actual flow rate of air through this passage 40 and another flow rate
50 sensor 64 installed in the exhaust gas recirculation passage 46 to provide a feedback signal F_3 indicating an actual flow rate of exhaust gas through this passage 46. These two flow rate sensors 62 and 64, too, are of the type detecting a
55 flow rate through corona discharge in a fluid subject to measurement and detection of a movement of ions formed in the fluid. This aforementioned high voltage generator 80 serves also as a common power supply to the additional
60 flow rate sensors 62, 64, and, where there is a need the pulse generator 82 too is utilized for these sensors 62, 64.

The construction of these flow rate sensors 58, 60, 62, 64 and the principle of their function will be
65 described with reference to Figs. 2—5.

As shown in Fig. 2, the air flow rate sensor 58 has a high potential electrode 58a which is pointed and is intruded into the induction passage 14, and a grounded electrode 58b which is disposed in the
70 induction passage 14 opposite and spaced from the former electrode 58a in the direction substantially normal to the flow of air in this passage 14. These two electrodes 58a and 58b constitute a pair of electrodes to bring about corona discharge. In
75 addition, another electrode 58c is disposed in the induction passage 14 at a distance downstream from the corona discharge electrodes 58a, 58b to collect a portion of ions formed by corona discharge in air and detect a current attributable
80 to the ions.

This flow rate sensor 58 functions on the following principle.

Corona discharge across the electrodes 58a and 58b brought about by the application of a high
85 voltage to the high potential electrode 58a causes partial ionization of air passing through a section where these electrodes 58a, 58b are disposed. A portion of ions formed in the air stream is collected by the grounded electrode 58b but the remaining portion is carried downstream by the
90 flow of air. The electrode 58c collects this portion of the ions, so that a current flows through a circuit including this electrode 58c. The intensity of this current increases as the quantity of ions arrived at the electrode 58c increases. The
95 proportion of the ions collected by the electrode 58b and ions arrived at the electrode 58c depends on the velocity of air flow in the passage 14: less ions are collected by the electrode 58b as the velocity becomes greater. The intensity of the
100 aforementioned current, therefore, increases as the velocity of the air flow, i.e. flow rate of air, increases. Thus, a current or voltage signal P_1 derived from the electrode 58c indicates an actual
105 flow rate of air in the induction passage 14. In other words, the control circuit 56 recognizes the air flow rate through electrical processing of this signal P_1 .

The fuel flow rate sensor 60 shown in Fig. 3 has
110 a high potential electrode 60a and a grounded electrode 60b. These electrodes 60a and 60b are disposed in the fuel passage 22 in the same manner as the electrodes 58a, 58b of the air flow rate sensor 58 to constitute corona discharge electrodes. However, the high potential electrode 60a of this sensor is not directly connected to the high voltage generator 80 but is connected to the
115 pulse generator 82. This flow rate sensor 60 includes an ion collection electrode 60c disposed in the fuel passage 22 at a distance downstream from the corona discharge electrodes 60a, 60b and another ion collection electrode 60c' located at a short distance downstream from the electrode 60c.
120

A momentary corona discharge occurs across the electrodes 60a and 60b upon application of a high voltage pulse to the high potential electrode 60a. A portion of ions formed by the corona
125 discharge will be collected by the grounded electrode 60b, but the remaining portion of the ions is carried downstream by the flow of fuel in
130

the passage 22. The ions carried downstream arrive at the two ion collection electrodes 60c and 60c' at a time interval determined by the distance between these two electrodes 60c, 60c' and the velocity of the fuel flow. Each of the two ion collection electrodes 60c and 60c' provides a pulse signal upon arrival of the ions, so that the output F_1 of this sensor 60 is two pulse signals with a short time interval therebetween. Since this time interval indicates the velocity of the fuel flow, the control circuit 56 can find the flow rate of fuel through the passage 22 from the output of the sensor 60, i.e. feedback signal F_1 .

As a modification of the sensor 60 in Fig. 3, it is possible to omit one of the ion collection electrodes 60c and 60c'. In such a case, both the application of a high voltage pulse to the electrode 60a and the arrival of ions at the single ion collection electrode are transmitted to the control circuit 56 since the velocity of the fuel flow is indicated by the time interval between the occurrence of corona discharge across the electrodes 60a, 60b and the arrival of the ions at the single ion collection electrode.

The flow rate sensor 62 for the secondary air passage 40 shown in Fig. 4 is identical with the air flow rate sensor 58 of Fig. 2 both in construction and in function. Corona discharge electrodes 62a, 62b of this flow rate sensor 62 correspond to the electrodes 58a, 58b of the flow sensor 58, and an ion collection electrode 62c in Fig. 4 corresponds to the electrode 58c in Fig. 2.

The flow rate sensor 64 for the exhaust gas recirculation passage 46 is shown in Fig. 5. This sensor 64 too has corona discharge electrodes constituted of a high potential electrode 64a and a grounded electrode 64b but has no additional electrode. In this sensor 64, the grounded electrode 64b is utilized also as a measurement electrode. When corona discharge is made across the electrodes 64a and 64b, a portion of ions formed in the exhaust gas by the corona discharge is collected by the grounded electrode 64b, and the proportion of the collected ions to the total ions depends on the velocity of the exhaust gas flow through the passage 46. For example, more ions are collected by the grounded electrode 64b as the velocity of the exhaust gas flow lowers. Accordingly a current or voltage signal F_2 derived from this electrode 64b indicates the flow rate of exhaust gas through the recirculation passage 46.

The illustrated applications of the above described three variations in the construction of corona discharge type flow rate sensors to the fluid passages 14, 22, 40 and 46 are merely by way of example. Each of these passages 14, 22, 40, and 46 may be provided with any of the flow rate sensors of Figs. 2 (or 4), 3 and 5. For air passages 14 and 40, however, the use of the flow rate sensor 58 of Fig. 2 (or 62 of Fig. 4) is preferable because of a relatively high intensity of the current derived from the ion collection electrode 58c (or 62c).

Fig. 6 shows the details of the flow control valve 44 provided to the secondary air passage 40. This valve 44 has a flexible diaphragm 44a which

supports a valve member 44b to regulate an effective cross-sectional area of the secondary air passage 40 and serves as a partition between a valve chamber 44d in the passage 40 and a vacuum chamber 44c external to the passage 40. A vacuum transmission passage 76 connects the vacuum chamber 44c to the induction passage 14 downstream of the throttle valve 16, and a spring 44e is installed in the vacuum chamber 44c to bias the diaphragm 44a toward the valve chamber 44d. The vacuum chamber 44c has a port 44f opening into the atmosphere, and a solenoid valve 44g is arranged to selectively open and close this port 44f in response to a control signal S_1 provided by the control circuit 56. As will be understood, the position of the valve member 44b can be controlled by controlling the admission of air into the vacuum chamber 44c through the port 44f to regulate the magnitude of vacuum acting on the diaphragm 44a.

As shown in Fig. 7, the construction of the exhaust gas recirculation control valve 48 is similar to that of the secondary air control valve 44 of Fig. 6. A diaphragm 48a which supports a valve member 48b serves as a partition between a valve chamber 48d in the exhaust gas recirculation passage 46 and a vacuum chamber 48c. A vacuum transmission passage 74 connects the vacuum chamber 48c to the induction passage 14 at a section downstream of the throttle valve 16, and a spring 48e is installed in the vacuum chamber 48c to bias the diaphragm 48a towards the valve chamber 48d. The vacuum chamber 48c has a port 48f opening into the atmosphere, and a solenoid valve 48g is arranged to selectively open and close this port 48f in response to a control signal S_2 provided by the control circuit 56. The position of the valve member 48b can be controlled by controlling the admission of air into the vacuum chamber 48c through the port 48f.

In the engine system of Fig. 1, the rate of fuel injection into the induction passage 14 is controlled in proportion to the air flow rate detected by the flow rate sensor 58 such that the resultant mixing ratio of air to fuel agrees with an optimum value taken as the target of the control. Such a target value of the air/fuel ratio is put into the control circuit 56 in advance of the use of the system. Preferably, the control circuit 56 is constructed to have the function of shifting the target of air/fuel ratio control depending on operating conditions of the engine 10. For example, an approximately stoichiometrical air/fuel ratio is employed as the target while the engine 10 is operated under normal or steady conditions, but the target of the control is shifted to a smaller air/fuel ratio (meaning a rich mixture) under both idling and accelerating conditions.

While the engine 10 is run, the quantity of air admitted into the engine 10 per unit time, i.e. the flow rate of air through the induction passage 14, increases and decreases according to the degree of opening of the throttle valve 16. By application of a high voltage from the power source 80 to the electrode 58a, the flow rate sensor 58 brings about

corona discharge in the flow of air and produces an electrical signal P_1 which represents the flow rate of air through the induction passage 14 as described hereinbefore. Fuel is injected from the injection nozzles 18 and/or 18' into the induction passage 14 due to a pressure difference between intake vacuum created in the induction passage 14 downstream of the throttle valve 16 and delivery pressure of the regulator pump 26 provided to the fuel tank 24. As described hereinbefore, the flow rate sensor 60 produces an electrical signal F_1 representing the fuel flow rate through the fuel passage 22 by application of a high voltage pulse to the electrode 60a.

The control circuit 56 compares an actual air/fuel ratio calculated from the signals P_1 and F_1 with the target value of air/fuel ratio and provides a control signal S_2 to the fuel supply regulation valve 32 such that the amount of fuel returned through the passage 30 is regulated so as to supply fuel to the injection nozzles 18, 18' at a rate appropriate to realization of an air/fuel ratio taken as the target value. When the air/fuel ratio calculated from the signals P_1 and F_1 is greater than the target value, the control circuit 56 commands the valve 32 to decrease the fuel flow rate through the return passage 30, and vice versa. Depending on the operating condition of the engine 10, the control circuit 56 provides a control signal S_2 to the selector valve 20 to effect its changeover so as to put into work only a selected one, or both, of the fuel injection nozzles 18, 18' for the reason as described hereinbefore.

Since the fuel supply regulation valve 32 is controlled based on an actual air flow rate in the induction passage 14 and an actual rate of fuel flow to the injection nozzles 18, 18', an actual air/fuel ratio can be kept in agreement with the target value even though there occurs great changes in the magnitude of intake vacuum, and, in case of a deviation of an actual air/fuel ratio from the target value, the deviation can be cancelled quickly. The use of the air flow rate sensor 58 and the fuel flow rate sensor 60 produces a marked improvement on the accuracy of fuel injection or air/fuel ratio control and affords an exceedingly good responsiveness to the fuel injection control system. As a consequence, the engine 10 exhibits improved performance particularly as regards driveability and specific fuel consumption in every range of operation conditions.

The principle of the function of the air flow rate sensor 58 holds on the assumption that the intensity of corona discharge or the degree of ionization of air can be kept constant. In practice, however, the intensity or efficiency of the corona discharge is influenced by humidity of air and lowers as humidity lowers, resulting in that an air flow rate represented by the signal P_1 is lower than an actual air flow rate because of a decrease in the quantity of ions formed by corona discharge. It is preferable, therefore, that the control circuit 56 has the ability of correcting the control signal S_2 so as to increase the rate of fuel flow to the injection

nozzles 18, 18' according as humidity lowers.

The relationship between volume flow rate and mass flow rate of air through the induction passage 14 depends on the temperature of air and atmospheric pressure: the mass flow rate lowers as the temperature rises and atmospheric pressure lowers. However, the control signal S_2 needs no correction in this connection since ions are collected by the electrode 58c at a rate proportional to the mass flow rate of air. In the case of utilizing a flow rate sensor of the time interval type as shown in Fig. 3 as the air flow rate sensor in the induction passage 14, certain errors will be produced in the detection of actual air/fuel ratio by the influence of air temperature and atmospheric pressure since the sensor of Fig. 3 detects only the velocity of a fluid flow. In such a case, it is preferable that the control circuit 56 has the ability of correcting the signal S_2 to eliminate the aforementioned errors based on the temperature and pressure signals P_1 and P_2 .

To further improve the accuracy of the air/fuel ratio control, the control circuit 56 may be made to have the ability of reflecting the specific weight of fuel (signal P_3), too, into the control signal S_2 , such that the rate of fuel flow to the injection nozzles 18, 18' lowers as the specific weight of fuel becomes greater.

Preferably, intake vacuum created in the induction passage 14 downstream of the throttle valve 16 is applied to the regulator pump 26, which delivers fuel from the tank 24, to control the delivery pressure of the pump 26 by the intake vacuum so that fuel may be injected from the nozzles 18, 18' under a constant pressure (difference between intake vacuum and the delivery pressure) and atomized always in an unvarying manner.

A target value of the flow rate of air through the secondary air passage 40 is also set in the control circuit 56 in advance of the use of the engine system. While the engine 10 is at work, air is admitted into the passage 40 by intermittent opening and closure of the reed valve 42 in compliance with pulsation of exhaust pressure. The air flow rate sensor 62 produces an electrical signal F_2 representing an actual air flow rate through the passage 40 (similarly to the sensor 58 in the induction passage 14) by application of a high voltage to the electrode 62a. The control circuit 56 compares the air flow rate represented by the signal F_2 with the target value of the flow rate of secondary air and provides a control signal S_4 to the secondary air control valve 44 so as to regulate actual flow rate of secondary air to the target value. When, for example, the air flow rate represented by the signal F_2 is greater than the target value, the control circuit 56 commands the solenoid valve 44g to enlarge an effective or average opening of the air admission port 44f of the vacuum chamber 44c. Preferably, the control signal S_4 takes the form of a series of pulses while the solenoid valve 44g is made to open (or alternatively close) the port 44f upon receipt of each pulse. Then an increased quantity of air can

be admitted into the vacuum chamber 44c through the port 44f by increasing the mark-to-space ratio of the pulses S_4 . The admission of an increased quantity of air into the vacuum chamber 44c results in that the diaphragm 44a is deflected towards the valve chamber 44d whereby the valve member 44b changes its position so as to decrease an effective cross-sectional area of the secondary air passage 40. When the air flow rate detected by the sensor 62 is below the target value, the control circuit 56 commands the solenoid valve 44g to lessen the admission of air into the vacuum chamber 44c.

The target value of the rate of secondary air supply through the passage 40 is set such that the oxidation of carbon monoxide and unburned hydrocarbons in the reactor 36 (which may contain an oxidation catalyst) is accomplished with best efficiency. Preferably the control circuit 56 is made to have the function of shifting the target of the control of secondary air depending on operating conditions of the engine 10.

A portion of the exhaust gas is recirculated through the passage 46 to the induction passage 14 with the object of suppressing the formation of nitrogen oxides in the combustion chambers of the engine 10. The rate of exhaust gas recirculation should be made to exactly agree with an intended value, i.e. optimum value, since not only the suppressive effect of exhaust gas recirculation on the formation of nitrogen oxides but also unfavorable influences of the recirculation on the operation of the engine 10 represented, for example, by driveability and stability of combustion depend significantly on the recirculation rate.

A target value of the rate of exhaust gas recirculation is set in the control circuit 56 in advance of the use of the engine.

The flow rate sensor 64 in the recirculation passage 46 produces an electrical signal F_2 , which represents an actual flow rate of exhaust gas through this passage 46, by application of a high voltage to the electrode 64a as described hereinbefore with reference to Fig. 5. The control circuit 56 compares an actual rate of exhaust gas recirculation calculated from the signals P_1 and F_2 (P_1 represents an actual rate of air feed to the engine 10) with the target value and provides a control signal S_5 to the exhaust gas recirculation control valve 48 such that the exhaust gas flows through the passage 46 at a rate appropriate to realization of an exhaust gas recirculation rate taken as the target value.

The control signal S_5 is preferably a series of pulses, and the manner of response of the flow control valve 48 to this signal S_5 is similar to the response of the secondary air control valve 44 to the signal S_4 . Downstream from the control valve 48, the exhaust gas recirculation passage 46 is connected to the induction passage 14 at a section downstream of the throttle valve 16. Accordingly the flow rate of exhaust gas through the recirculation passage 46 is influenced by the magnitude of intake vacuum. However, the rate of

exhaust gas recirculation in the system of Fig. 1 does not significantly deviate from the target value by this reason since a change in the exhaust gas flow rate through the passage 46 is quickly detected by the flow rate sensor 64, followed by regulation of the position of the valve member 48b.

Since the exhaust gas recirculation rate is the proportion of recirculated exhaust gas to air admitted into the engine 10, the control of exhaust gas recirculation in the system of Fig. 1 can be achieved with higher accuracy by reflecting humidity, air temperature and atmospheric pressure into the control signal S_5 in the same way as in the control of fuel injection rate.

The specific weight of the exhaust gas becomes smaller as the exhaust gas temperature becomes higher, so that the mass flow rate of exhaust gas through the passage 46 lowers according as the exhaust gas temperature rises even when the control valve 48 is kept in a definite state. In the case of using a flow rate sensor of the time interval type shown in Fig. 3 as the flow rate sensor in the exhaust gas recirculation passage 46, therefore, corrections should be made to the control signal S_5 based on the exhaust temperature signal P_4 .

The control circuit 56 has the function of shifting the target value of the exhaust gas recirculation rate depending on operating conditions of the engine 10. Furthermore, it is preferable that the exhaust gas recirculation control valve 48 is completely closed while the temperature of cooling water (signal P_3) is below a predetermined temperature, e.g. 50°C, because it is desirable to interrupt the recirculation of exhaust gas for the purpose of promoting warmup of the engine or decreasing the amounts of carbon monoxide and unburned hydrocarbons in the exhaust gas while the engine temperature is too low to allow the formation of a large quantity of nitrogen oxides.

CLAIMS

1. An electronically controlled internal combustion engine system comprising:
an internal combustion engine including means for defining an induction passage which is provided with a throttle valve linked with an accelerator and means for defining an exhaust passage;

at least one fuel injection nozzle opening into said induction passage at a section downstream of said throttle valve;

means for defining a fuel passage connecting said at least one fuel injection nozzle to a fuel tank;

an electrically operated valve means associated with said fuel passage to regulate the rate of fuel supply to said at least one fuel injection nozzle;

a first flow rate sensor disposed in said induction passage to detect an actual flow rate of air passing therethrough;

a second flow rate sensor disposed in said fuel passage to detect an actual flow rate of fuel passed

to said at least one fuel injection nozzle, both said first and second flow rate sensors being of a type making corona discharge in a fluid flow to detect a movement of ions formed in the fluid by the corona discharge as an indication of the velocity of the fluid flow;

a high voltage source connected to said first and second flow rate sensors; and

an electronic control means for controlling said valve means based on the outputs of said first and second flow rate sensors such that the ratio of an actual flow rate of fuel detected by said second flow rate sensor to an actual flow rate of air detected by said first flow rate sensor agrees with a target value.

2. An engine system as claimed in Claim 1, wherein said at least one fuel injection nozzle is a combination of at least two injection nozzles all connected to said fuel passage with the provision of a selector valve means for selectively interrupting the supply of fuel to a portion of said at least two injection nozzles in response to a control signal provided by said control means based on the output of said first flow rate sensor.

3. An engine system as claimed in Claim 2, wherein a metering orifice is formed in said fuel passage, the system further comprising means for defining a fuel return passage which branches from said fuel passage at a section downstream of said orifice and terminates at said fuel tank, said valve means being an electrically operated flow control valve provided to said fuel return passage.

4. An engine system as claimed in Claim 2, wherein said first flow rate sensor comprises a pair of electrodes disposed in said induction passage with one of said electrodes connected to said high voltage source and an ion collection electrode disposed in said induction passage at a distance downstream from said corona discharge electrodes to collect a portion of ions formed in air by the corona discharge such that the amount of ions collected by said ion collection electrode increases as the flow rate of air increases.

5. An engine system as claimed in Claim 2, wherein said first flow rate sensor comprises a pair of corona discharge electrodes disposed in said induction passage with one of said electrodes connected to a high voltage pulse generator which is connected to said high voltage source and an ion detection electrode disposed in said induction passage at a distance downstream from said corona discharge electrodes to detect the arrival of at least a portion of ions formed in air by the corona discharge such that the output of said first flow rate sensor indicates a length of time said ions required to travel a distance terminating at said ion detection electrode.

6. An engine system as claimed in Claim 2, wherein said second flow rate sensor comprises a pair of corona discharge electrodes disposed in said fuel passage with one of said electrodes connected to said high voltage source and an ion collection electrode disposed in said induction passage at a distance downstream from said corona discharge electrodes to collect a portion of

ions formed in fuel by the corona discharge such that the amount of ions collected by said ion collection electrode increases as the flow rate of fuel increases.

7. An engine system as claimed in Claim 2 or 4, wherein said second flow rate sensor comprises a pair of corona discharge electrodes disposed in said fuel passage with one of said electrodes connected to a high voltage pulse generator which is connected to said high voltage source and an ion detection electrode disposed in said fuel passage at a distance downstream from said corona discharge electrodes to detect the arrival of at least a portion of ions formed in fuel by the corona discharge such that the output of said second flow rate sensor indicates a length of time said ions required to travel a distance terminating at said ion detection electrode.

8. An engine system as claimed in Claim 1 or 2, further comprising means defining an exhaust gas recirculation passage which interconnects said exhaust passage to said induction passage to recirculate a portion of exhaust gas exhausted from said engine to said induction passage, an electrically operated flow control valve associated with said recirculation passage, and a third flow rate sensor which is disposed in said recirculation passage to detect an actual flow rate of exhaust gas recirculated through said recirculation passage and is of a type making corona discharge in a fluid flow to detect a movement of ions formed in the fluid by the corona discharge as an indication of the velocity of the fluid flow, said high voltage source being connected also to said third flow rate sensor, said control means having the function of controlling said flow control valve based on the outputs of said first and third flow rate sensors such that the ratio of an actual flow rate of the recirculated exhaust gas detected by said third flow rate sensor to an actual flow rate of air detected by said first flow rate sensor agrees to a target value.

9. An engine system as claimed in Claim 8, wherein said third flow rate sensor comprises a first electrode which is disposed in said recirculation passage and is connected to said high voltage source and a second electrode which is grounded and disposed in said recirculation passage so as to be opposite said first electrode in the direction substantially normal to the axis of said recirculation passage such that said second electrode serves as an ion collection electrode which collects a portion of ions formed in the exhaust gas by the corona discharge, said portion of ions decreasing with increase in the flow rate of the recirculated exhaust gas.

10. An engine system as claimed in Claim 9, wherein said flow control valve comprises a valve chamber formed in said recirculation passage, a diaphragm arranged to serve as a partition between said valve chamber and an external vacuum chamber, a valve member supported by said diaphragm and disposed in said valve chamber to vary an effective cross-sectional area of said recirculation passage, a conduit connecting

said vacuum chamber to said induction passage at a section downstream of said throttle valve, a port through which air is admitted into said vacuum chamber from the atmosphere and a solenoid valve to intermittently open and close said port, said control means controlling the function of said solenoid valve.

11. An engine system as claimed in Claim 8, further comprising a reactor which occupies a portion of said exhaust passage to remove noxious components from the exhaust gas, means for defining a secondary air admission passage arranged to introduce atmospheric air directly into said exhaust passage at a section upstream of said reactor, a reed valve arranged to intermittently open and block the communication of said secondary air admission passage with the atmosphere in response to pulsation of exhaust gas pressure in said exhaust passage, another electrically operated flow rate control valve associated with said secondary air admission passage at a section downstream of said reed valve, and a fourth flow rate sensor which is disposed in said secondary air admission passage at a section downstream of said reed valve to detect an actual flow rate of secondary air and is of a type making corona discharge in a fluid flow to detect a movement of ions formed in the fluid by the corona discharge as an indication of the velocity of the fluid flow, said high voltage source being connected also to said fourth flow rate sensor, said control means having the function of controlling said another flow control valve based on the output of said fourth flow rate sensor such that an actual flow rate of secondary air detected by said fourth flow rate sensor agrees with a target value.

12. An engine system as claimed in Claim 11, wherein said fourth flow rate sensor comprises a pair of corona discharge electrodes disposed in said secondary air admission passage with one of said electrodes connected to said high voltage source and an ion collection electrode disposed in

said secondary air admission passage at a distance downstream from said corona discharge electrodes to collect a portion of ions formed in secondary air by the corona discharge such that the amount of ions collected by said ion collection electrode increases as the flow rate of secondary air increases.

13. An engine system as claimed in Claim 11, wherein said fourth flow rate sensor comprises a pair of corona discharge electrodes with one of said electrodes connected to a high voltage pulse generator which is connected to said high voltage source and an ion detection electrode disposed in said secondary air admission passage at a distance downstream from said corona discharge electrodes to detect the arrival of at least a portion of ions formed in secondary air by the corona discharge such that the output of said fourth flow rate sensor indicates a time interval between the application of a high voltage to said corona discharge electrodes and the arrival of at least a portion of said ions at said ion detection electrode.

14. An engine system as claimed in Claim 11, wherein said another flow control valve comprises a valve chamber formed in said secondary air admission passage, a diaphragm arranged to serve as a partition between said valve chamber and an external vacuum chamber, a valve member supported by said diaphragm and disposed in said valve chamber to vary an effective cross-sectional area of said secondary air admission passage, a conduit connecting said vacuum chamber to said induction passage at a section downstream of said throttle valve, a port through which air is introduced into said vacuum chamber from the atmosphere and a solenoid valve to intermittently open and close said port, said control means controlling the function of said solenoid valve.

15. An electronically controlled internal combustion engine system substantially as herein described with reference to the accompanying drawings.

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